## THE PRACTICAL IMPORTANCE OF CLIMATIC CYCLES IN ENGINEERING

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Science has furnished a vast amount of information regarding the ancient and recent changes of climate. Little, if any, of this knowledge has found its way into the practical arts, such as hydraulic engineering. Works for the control of water are based on records of precipitation, run-off, and water levels and the fluctuations thereof; but thus far no practical use has been made of climatic science for that purpose.

The reasons are twofold: First, the theories of climatic changes from the Paleozoic to the present are still largely controversial; second, the amplitudes of recurring cycles are generally considered too small to be of any importance.

1. SCIENCE OF CLIMATIC CHANGES STILL IN FORMATIVE STATE.

*Oswald Heer* (1) found that a uniform warm climate existed from the early Carboniferous to the late Cretaceous, based on fossil flora found in Greenland and Spitzbergen. Stigmaria, Calamites, and other Carboniferous flora, as well as Oleander, Magnolia, Ficus from the Cretaceous, once grew in abundance in those polar regions. A division of climate according to latitude is visible, according to Heer, only in the late Cretaceous and the Miocene flora, also found in the polar regions. Heer states: "Nirgends ist die geringste Spur einer Gletscherzeit wahr zu nehmen." This view is opposed by *Melchior Neumayer* (2), who finds many proofs of zonal distribution in the Jurassic and the Cretaceous; also the Carboniferous flora is said to show zonal characteristics. *Doctor Wieland* (*Yale*) states that growth rings have been found in the upper Mid-Devonian Callixylon, as well as in a Carboniferous Cordaites as far south as Texas, which would indicate the existence of seasons long before the Miocene (3). The strongest argument against Heer's uniform climate is the occurrence of glaciation in the Carboniferous. On the other hand, Professor Hobbs holds that Heer's major thesis is still correct.

Similar opposite views prevail concerning recent climatic fluctuations. *Brückner* was severely criticized by the meteorologist *Schreiber* (4) while, on the other hand, *C. E. P. Brooks* states that Brückner's views were immediately accepted (5). *Henry* finds (6), using Brückner's methods on data of the United States since 1890, that the former's results are only partly verified.

The same differences are also found in recent opinion on the relation between the solar cycle and climate. *Huntington* (7) and *Douglass* (8) find relations well established, while *Charles G. Abbott* (3) and *H. Norris Russell* (10) do not. Regarding methods of analysis, divergent opinions also exist. *Bigelow's* (9) and *Clough's* (11) views are not shared by *G. T. Walker*, who apparently does not accept (12) variable cycles, and considers harmonic analysis applicable on weather data, although the necessary mathematical conditions are in that application not satisfied, different results from different parts of the same record are obtained therewith, and extensions do not agree with subsequent observations (13). Instead of a small number of variable cycles, far enough apart to be distinctly separable, *C. E. P. Brooks* prefers to discuss 18 harmonic elements in the Nile floods (14) and *Brunt* 44 harmonic elements in rainfall (15).

Hence, finding that the science of climatic changes is still in formative condition, practical engineering has thus far abstained from applying controversial theories and methods.

2. AMPLITUDES OF CLIMATIC CYCLES ARE SMALL AS COMPARED WITH LOCAL AND MOMENTARY CHANGES.

If cycle studies had produced results in meteorology, their use would probably have penetrated into the engineering field, but thus far they have been of no aid. It has tacitly been assumed that the same results would also be obtained in hydraulic engineering. According to *C. F. Marvin:* The primary obligation of the Weather Bureau is to forecast the weather, and the principle of cycles might be used in this work if the cyclical recurrences are real and the effects important. Real cycles of very small amplitudes would have very little forecasting value (3).

The Brückner cycle of temperature and pressure, as well as the 11-year cycle, have amplitudes altogether too small to be of any significance for forecasting weather. The variation in temperature is on the order of 1° C. or less. On the other hand, a 15° C. difference in the temperature of the same day is a common occurrence (16). The secular variation in pressure is not more than a few millimeters, and the daily changes during storms may be fifteen times as much.

For elements which are measured by accumulation, such as rainfall, the secular amplitudes are larger, although here also the many fortuitous daily changes surpass in amplitude the secular variations of yearly rainfall. For agriculture a severe passing drought, hailstorm, or cloud-burst is of more immediate local concern than a slight change in total rainfall over many years. While the amplitudes of long rainfall cycles are greater than those of either temperature or pressure, it has been impossible to make practical use thereof in weather fore-

casting, because the erratic and fortuitous changes in rainfall are yet many times greater. Repeated investigations have established many possible sources of errors in rain-gage readings. The influence of gage size, exposure, elevation above ground, and wind velocity is well known. The erratic distribution of rainstorms, such as occurred at Cambridge, Ohio, on July 16, 1914, is amply recorded in the annals of the United States Weather Bureau and was recently investigated by Professor *Kassatrine*, of Moscow (17). Study of long cycles in rainfall is hampered by the scarcity of reliable long records, as illustrated by *Desmond Fitzgerald* in the Cochituate (18) records of the Boston water supply, and by *R. Siedek* in discussing the old "Brander" rain gage of the Austrian hydrographic service (19).

Summarizing, it may be said that because cycles in temperature, pressure, and rainfall are largely obscured and surpassed in amplitude by the local and momentary changes, they are of no practical use in weather service.

3. BASIC DIFFERENCE BETWEEN HYDROGRAPHIC AND METEOROLOGICAL DATA.

This conclusion of practical meteorology has been transferred sine qua non to engineering, although the conditions are modified to such extent in hydrographic data that the situation is completely reversed. Here secular amplitudes occasionally surpass the amplitudes of local and momentary changes, and, far from being ob-
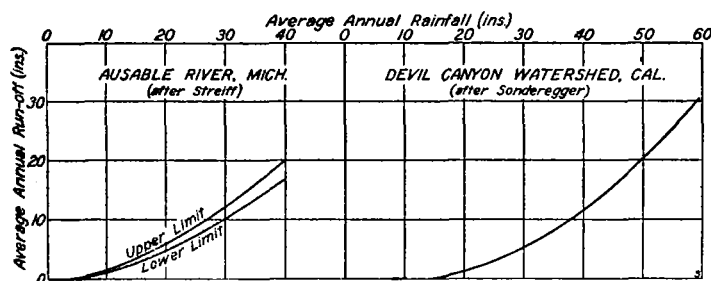


FIGURE 1.—Amplifying effect of run-off

scured by the latter, are often visible by mere inspection of the record. On account of this more favorable proportion between the secular and the fortuitous momentary amplitudes the chances for a successful elimination of controversy are more favorable in the application of climatic sequences to hydraulic engineering than to weather service. Although the recent fluctuations in climate are small, it is not necessary that these changes should be large in order to become of great practical importance in hydraulic engineering.

Weather service deals largely with *momentary* values and changes. The task of hydraulic engineering is the control and conservation of water; hence it deals largely with *cumulative* values. Precipitation is collected on large drainage basins and partially runs off. The run-off is again accumulated in lakes and storage basins. The storage quantities and water elevations represent a repeated accumulation, and by this cumulative process small secular differences, unimportant for weather service but sustained over long periods, become great and important effects.

The difference in evaporation from and flow into a lake basin may be delicately small, but the unlimited time factor may nevertheless cause cumulative effects of enormous magnitude. The Great Salt Lake fell 14 feet between 1875 and 1905, or in 30 years, while the climate was merely somewhat drier than usual, and the daily

weather changes with the usual hail, rain, and thunder storms probably were not noticeably different than at present with a rising lake level. At the same rate a fall of several hundred feet might, in a sufficiently deep lake, well take place in 500 years; post-glacial lacustrine changes might well occur within the limits of small secular changes of no account in weather service, but sustained through thousands of years.

The post-glacial changes nevertheless were very great. The Great Salt Lake shrunk from 19,750 to 1,750 square miles since the retreat of the ice. The diluvial Lakes Agassiz and Iroquois disintegrated into the present much smaller Lakes Winnipeg and Erie (20). *Nachtigal* investigated the enormous extent of the diluvial Lake Tchad in Africa (21), while *von Richthofen* has carefully collected evidence of the much greater diluvial areas of Lakes Pangong, Chamoriri, Lob-nor, and many others in Turkestan and Tibet (22). According to *Mucshketov*, the Caspian Sea had more than twice its present size, and still has ancient beaches 180 feet above its present level (23); a connection existed through the Manytch Valley with the Black Sea and also with Sea of Aral, then more than three times its present size.

The streams which feed such lake basins are also the cumulative result of rainfall on a large drainage area. The erratic nature of rain-gage data is thoroughly modified in stream flow. A drainage area of 10,000 square miles has a collecting surface 805,000,000,000 times greater than an 8-inch rain-gage. Ground storage aids in equalizing unequal distribution of rain as to place and time. An example of the equalizing effect of drainage areas on a huge scale is furnished by the Amazon River. Flowing along the Equator, its northern and southern tributaries are alternately in flood during the first and second half of the year, so that the flow of the main stream is equalized throughout the year (24).

In addition to the equalizing effect of large drainage areas, ground and lake storage, the river functions as an amplifyer of the variations of annual rainfall. This is illustrated in the examples of Figure 1, giving the relation between annual rainfall and run-off. As examples are chosen the Ausable River, in Michigan, compiled by the writer, and the Devil Canyon watershed in California, given by *Sonderegger* (25). The run-off increases faster than the rainfall; a variation of one-third in rainfall may double the run-off, the latter increasing *three times faster* than the rainfall. The river functions exactly in the manner of an amplifying radio tube, the characteristic curves having the same shape.

On account of these fundamental differences between hydrographic and weather data, the importance of climatic cycles, such as the Brückner and the 11-year cycle, is not to be found in meteorology, but in hydraulic engineering. It is measurable with current meter and surveying instruments rather than with thermometer, barometer, or rain gage.

These fundamental differences are still overlooked in hydraulic engineering. Supposedly in accordance with the great measure of fortuity prevailing in the ceaseless weather changes, a fortuitous sequence of stream flow has been adopted in hydraulic engineering. The actually existing amplification of the small secular changes due to the cumulative nature of hydrographic data is not clearly recognized. Because the climatic cycles thus far found were, rightfully, disregarded in practical meteorology, they were also disregarded by the engineers, although the conditions are fundamentally and totally different.

The difference was carefully noted, however, by Professor Brückner. In Chapter IX of his work, Klimaschwankungen seit, 1700, he discusses the "theoretical and practical importance of the climatic cycle." In this chapter only hydraulic phenomena and activities covered by hydraulic engineering are quoted as examples illustrating the importance of the climatic cycle.

Brückner describes the secular changes in glaciers, lakes, and swamps; the number of floods; channel depth for interior navigation; ground water and sanitation; agriculture, especially in the semiarid regions. These subjects are covered by drainage, sanitary, irrigation, rivers and harbors engineering. In Alpine countries glaciers are now carefully studied by hydroelectric engineers.

The remainder of Chaper IX contains a scientific discussion of the changes in level of oceans, the choice of climatological mean values, and of existing literature. It is significant that the erudite and ingenious author of Climatic Changes thus demonstrated that the cycle which he found by studying the records of 804 stations and 36,900 observation years is principally of importance in hydraulic engineering. Although it has no value for the meteorologist in forecasting the weather, the old work of Brückner, newly interpreted and properly applied becomes a veritable handbook for the hydraulic engineer,

4. IDENTITY OF THE BRÜCKNER CYCLE.

The interpretation referred to involves the relation. between the climatic and solar cycle. Finding successively a cycle in lake levels, rainfall, pressure, and temperature, Brückner naturally suspected the cause of these to be solar variation. Investigation of such relation began shortly after the discovery of the solar cycle by Schwabe. Brückner quotes 36 authors on the relation between solar and terrestrial cycles. Since then the number has greatly increased, but no unanimous verdict has been reached.

Brückner recognized the existence of several long cycles. "Three systems of oscillations exist which are superimposed upon and interfere with each other * * *" (p. 323). He also states that the longest one is a "diluvial" cycle; only the two others control historic times. However, using only a statistical compilation of 5-year averages, he does not find a relation with the Wolf numbers. He states, nevertheless: "I do not deny the influence of sun spots on weather. On the contrary, the above table shows distinctly that influence in certain details although the longer variations seem independent * * *. Much speaks for the theory discussed above, that this force resides in the sun, that therefore the solar radiation shows a 36-year period independent of sun spots. It may cause surprise that such oscillations of solar radiation hitherto have escaped attention; at least I do not know of any phenomena on the solar disk having a period of 36 years. But the measurement of solar radiation is at present (1890) still very imperfect. We even can not demonstrate differences which are known to exist and can be computed. The quantity of heat received on earth is one-fifteenth greater in perihelian than in aphelian, yet this difference has not yet been measured. How much easier, then, could a secular difference in intensity have escaped attention, the amplitude of which is probably less than that and the duration many decades?"

The difference which Brückner finds between his own figures and the Wolf numbers is only apparent. It is mainly due to his exclusive use of 5-year averages, which

is insufficient to segregate the cycles. In a previous study (26) agreement between the two was illustrated with several examples. It is of interest to further examine Brückner's own figures of wine harvest and temperature. The curves are platted in accompanying Figure 2. By using the previously given method (26) they can be segregated into the "Brückner cycle" and the "secular cycle," as shown. It may be seen that with a slight displacement of the wine-harvest curve which Brückner already noted, both are in satisfactory agreement.

In Figure 3, which is an extension back to 1750 of Figure 3, page 293, M.W.R. 1926, these curves appear to run parallel with the Wolf numbers. Brückner does not segregate the Brückner from the secular cycle, and hence his length of period is different. He designates the interval 1756–1805 as one period, whereas in reality it consists of two periods of the Brückner cycle, but only one of the secular cycle. He arrives in this manner at a greatly varying length of the Brückner cycle.

Prior to the platted records Brückner derives his length of period from mere tabulations of "cold" and "warm" periods, which should be regarded uncertain. Adopting
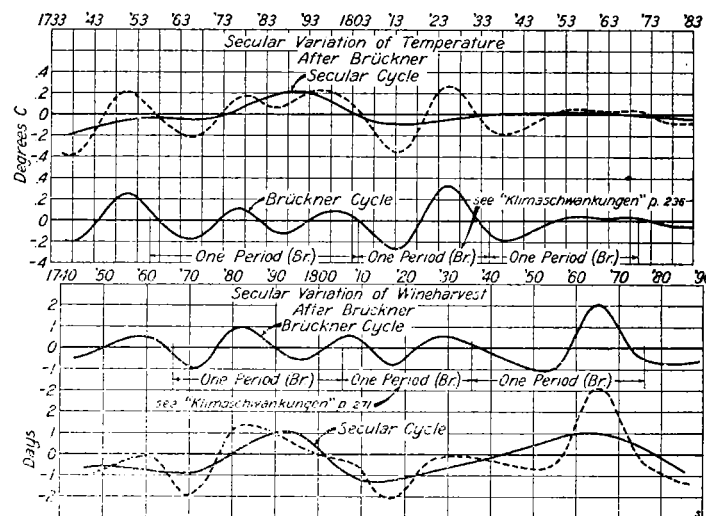


FIGURE 2.—Brückner's figures of temperature and wine harvest

the above separation of the Brückner and secular cycle, the average length since 1770 is 24.5 years; since 1860, 22.6 years.

The 22.6-year period seems to become the accepted solar cycle instead of the 11-year cycle; striking is the great regularity of the cycle since 1860, as pointed out by *Abbott* (3). Also, we have since 1860 three times a *high* 11-year maximum following a *low* 11-year maximum. This has been referred to by *Clements* (3).

But is this reversal of polarity permanent? Prior to 1860 the alternately high and low maximum of the 11-year cycle is lost. Whether this is due to greater uncertainty of the Wolf numbers prior to 1860 or to an "evolution of the law," as discussed by the celebrated mathematician, *Henry Poincaré* (31), will be decided in the future. Should the permanency prove true, then the Brückner cycle is the polarity cycle of the sun spots, superimposed on the secular cycle.

The secular cycle is also variable. From all data available the three last periods are estimated 70, 60, and 90 years in length, or an average of about 73 years. The first period is derived from Douglass's sequoia curve (1911, 11 trees).

While Brückner, with much ingenuity, has sought to systematize the climatic oscillations of long duration, it appears that the conditions are not as simple as he describes them. The alleged reversal of the cycle over the oceans can not be generalized. Undoubtedly the Gulf Stream has much to do with the reversal of the cycle over the oceans as he found, for, while existing on the west and east shore of the Atlantic, it is absent along the California coast. Apparently the Brückner cycle changes phase with geographical location in greater measure than he found.

Since Brückner's time 40 more years of observation are available, but still more are required to properly establish the relations here discussed. The above should therefore be considered tentative and subject to future confirmation.

As Brückner already emphasized, the phase of the climatic cycle varies with geographical location. This

beach will cause numerous secondary waves and ripples The division into continents and oceans, warm and cold ocean currents, plateaus and mountain ranges, influence the course of atmospheric circulation. A standard regimen of circulation can be visualized only as existing within wide limits. The records indicate greater regularity in those from plains than from mountainous regions.

Such a standard system of multiannual oscillations is submerged in the daily weather changes, but becomes apparent in the cumulative effects of run-off and storage. While meteorologists, therefore, rightfully claim that a relation between sun spots and weather has not been successfully demonstrated, that claim can not be transferred to hydrographic records. These, often in unison with the Wolf numbers, display oscillations of far-reaching economical importance, which follow a course apparently (but only apparently) independent from the also economically important weather changes with their ceaseless succession
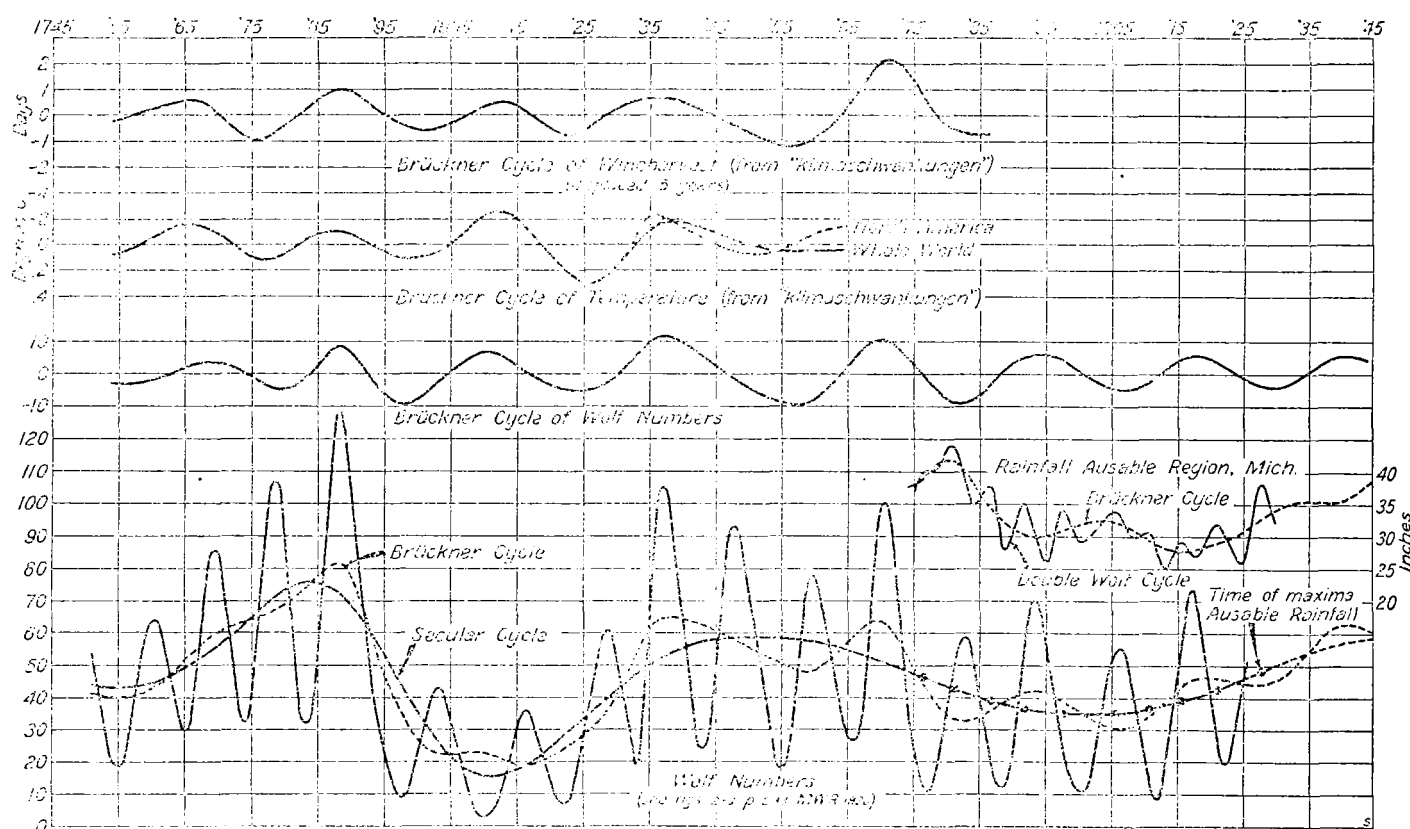


FIGURE 3.—Correlation of Wolf numbers and Brückner's data

seemingly is in accordance with the results of *Kullmer*, who shows the path of cyclones to vary with the solar cycle (32).

In a previous study it was shown that not only the Brückner cycle can be identified in the Wolf numbers, but the smaller cycles as well (26). Besides the two cycles named above, the *11-year*, the "*double sun-spot cycle*" (after Douglass) of half that period, and the "*Clough*" cycle are the fundamental units to be found in nearly every record. The latter can often be separated into two cycles of nearly one-quarter and one-eighth of the 11-year cycle; but this is of no practical importance.

It should not be inferred that a universal and rigid applicability should be attributed to this conception. In some regions the relations are clearer than in others. A stone thrown into a quiet pond will cause a concentric and symmetric wave, but the irregularities of an adjacent

of frosts, hot and cold waves, rain, hail, snow, and thunder storms, droughts, and cloud-bursts. The latters' hectic succession is merged into a residual system of slow but certain sequences, which at least in some regions can be correlated clearly with the Wolf numbers.

5. EFFECTS OF THE CLIMATIC CYCLES

The lake and ground-water levels rise and fall with these cycles. The Great Salt Lake (fig. 4) is again nearing a period of expansion similar to that prevailing between 1860–1875. An increase in area of some 400 square miles around 1945 may well be expected. The damage thereby caused to riparian owners, to roads, bridges, quays, wharves, and docks is obvious. Riparian structures are usually erected oblivious of the slow but sure rise and fall of the water level, which are not apparent to the uninformed. Only in locations where the limits occur

frequently, as happens along the rivers, are they heeded. The trestle of the Southern Pacific Railroad across the Great Salt Lake will probably have to be raised, as well as the structures of bathing resorts near Salt Lake City.

The Great Salt Lake began to rise simultaneously with the extension of the Mormon settlements in Utah. *Cyrus Thomas* and *Hough* (**27**, pp. 71 and 92) ascribed the improvement of climate to agriculture. The rivers and brooks feeding the lake carried more water than usual; a greater amount could be diverted for irrigation purposes. This was supposedly due to increased area under cultivation, causing increased evaporation and consequently rainfall. The theory proved false when after 1875 the lake fell continuously until 1905, and the irrigated area had to be reduced. Since then the lake has risen, and the next period until around 1945 will probably be characterized by improved grazing and farming conditions all through the arid West.

Typical for the last downward swing of the secular cycle, beginning around 1875, minimum around 1905, and next maximum probably around 1945–1950, is the following opinion based on extensive observation during the last 25 years (**28**):

Prior to the advent of the white man erosion was a matter of minor importance in the arid Southwest. At that time there was generally an excellent grass carpet which retarded run-off and prevented erosion. Overgrazing by the cattle and sheep industry has depleted, in fact, almost exterminated, the grass carpet over large areas, resulting in erosion and denudation. Rapid restoration of overgrazed areas has taken place during a series of wet years following a series of dry years. * * *

*Kirk Bryan* (**29**), finding geological evidence of erosion long before overgrazing by the white man's cattle, states: "It appears that these cyclic changes have a common and doubtless climatic cause. The introduction of live-stock and the ensuing overgrazing should be regarded as a mere trigger pull, which timed a change about to take place." At the desert border a persistent, cumulative though small deficiency of rainfall just below the necessary minimum gradually overcomes the tenacity of life of the vegetation. Plant life perishes, followed by wind erosion, denudation, and desolation. This undoubtedly is hastened but not caused by overgrazing.

Brückner states: "During minima the dry and warm years will be somewhat more frequent than the moist and cool ones. A forecast of this cycle is of no significance for Europe, as here the variations of rainfall, which are of principal importance, are rather moderate. Of value such forecast would be for the continental regions, where the variations of rainfall are much more accentuated; for Siberia, Australia, and, above all, for the interior of North America." Brückner also gives statistics to show that while in the continental regions the wet period of the Brückner cycle accelerates agriculture, the reverse effect occurs in the normally humid maritime climate of Europe.

The Great Lakes exhibit the Brückner cycle in close agreement with the rainfall; but as the lake level is proportional to the total inflow, the cycle of lake level lags one-quarter period against the cycle of rainfall. The 11-year cycle, of small amplitude in the rainfall of these regions, again is enlarged in the lake levels. At present a maximum prevails; the next maximum, expected to occur around 1940, will, on account of the rise in the Brückner cycle, probably be about a foot higher than the present maximum.

In this region the practical consequences of the faint cycle in climate are measurable in millions of dollars. The value of 1 foot additional draft to navigation is estimated at $5,000,000 (**30**).

Prior to 1925 the continually falling lake level caused widespread damage and was repeatedly investigated and reported upon. This continued damage finally caused six States and the Dominion of Canada to prefer legal action against the city of Chicago, the Chicago Drainage Canal supposedly having caused the lowering of the lake levels. The cost of this legal struggle and the resulting compulsion of the city of Chicago to build the largest sewage-disposal plant in existence represent huge expenditures.

Private owners, real-estate enterprises, large industrial concerns, as well as municipalities along the 5,400 miles of shore line of the Great Lakes, suffered great damage on account of the rise in the lake level since 1925. Not guided by "climatic engineering," construction activity crowds against the existing shore lines, following these in their slow advances and retreats, and occasionally falls into the "climatic trap." In certain sections the spectacle of new residences surrounded by water is frequently seen. A large lumber concern was forced to abandon its yards.
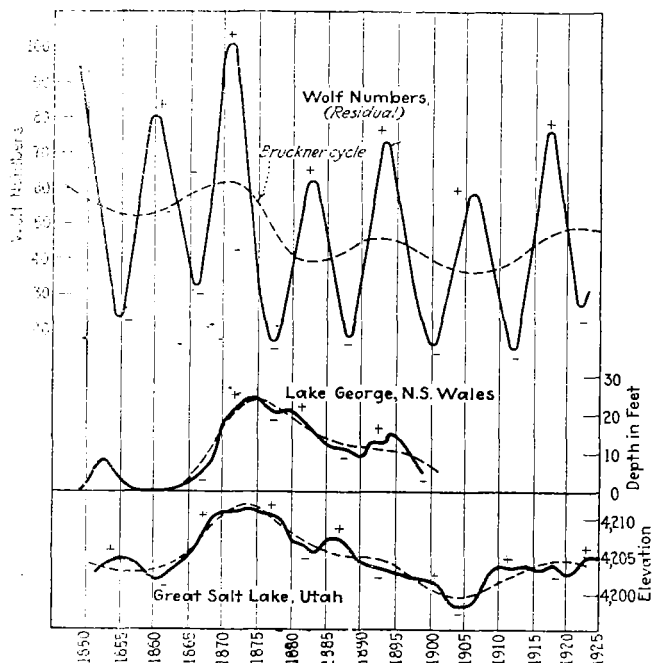


FIGURE 4.—Great Salt Lake, Lake George, Australia, and Wolf numbers

In another city a large public-utility corporation installed at great cost a booster pumping plant for the circulating water of its superpower station, but due to subsequent rise in level the large investment was never used. The varying yield of streams also affected water power. Another public utility, fearing continuation of the dry years prior to 1926, hurriedly installed additional boiler capacity to take care of the reduced hydroelectric output, but the large investment proved superfluous for the original purpose.

Such are the far-reaching effects of faint cycles in climate, having an amplitude of no importance in daily weather service.

## 6. APPLICATION OF CORRELATION WITH WOLF NUMBERS.

*Seth B. Nicholson* (**3**) advocated the use of the Character Figures of Solar Phenomena, published in Zurich, instead of the Wolf numbers, for comparison with terrestrial cycles. According to Mr. Nicholson, the Wolf number is equal to the number of spots plus ten times the number of groups; and it should therefore not surprise the investigator of cycles that such an arbitrary constant

should fail to give consistent results throughout. Nevertheless, a surprising agreement with terrestrial cycles may be found in some records.

The unbroken sweep of open country in the Great Lakes region seems especially favored with a regular system of atmospheric circulation. From the rain-gage readings of the United States Weather Bureau the cycle was derived already 30 years ago by the prominent hydrologist, Robert E. Horton. In Water-Supply Paper No. 30, 1899, Mr. Horton discusses run-off and water power
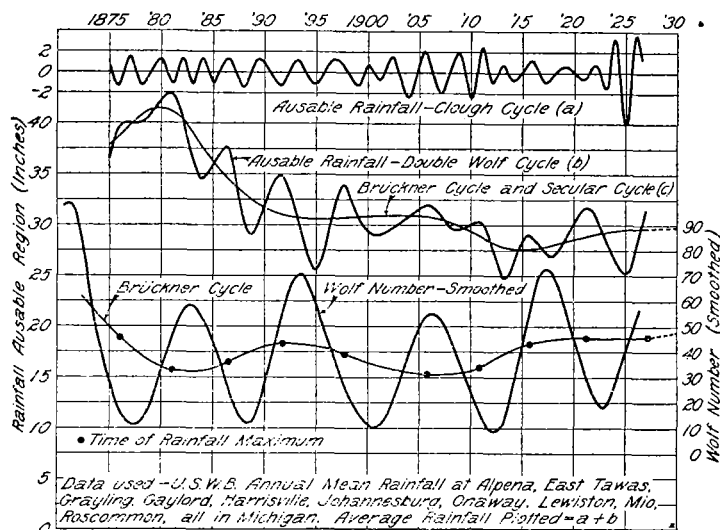


FIGURE 5.—Rainfall, Ausable region, Michigan

of the Kalamazoo River, and therein clearly recognizes a cycle which, after 30 more observation years, proves to be the double sun-spot cycle. Mr. Horton predicted the next minimum to take place in 1901. The forecast was made in 1898, or three years in advance. Figure 5 shows that this forecast was exactly verified. Figure 5 is a graph of the rainfall in the Ausable region of the Southern Peninsula of Michigan, computed from data furnished by Mr. D. A. Seeley, United States meteorologist in Lansing. The average of 10 stations is resolved into the "Clough cycle" and a residual, which is composed of the double sun-spot cycle superimposed on the Brückner and the secular cycle. The 11-year cycle is very small in this record.

It should be emphasized that an average of many stations is needed to eliminate fortuitous errors, distributed, according to Hann, over an area not more than 200 miles in diameter. The Ausable watershed is only some 1,600 square miles.

It may be seen that the cycle discovered by Horton has faithfully recurred since 1899. Indicating the maximum of rainfall on the secular cycle of the Wolf numbers with a black dot, it may be seen that this occurs always before each maximum or minimum of the 11-year cycle. It has faithfully recurred ten times during the last 54 years. We have here in reality a double sun-spot cycle.

Transferring the cycle to Figure 3, the inverse relation of the Brückner cycle in Wolf numbers and rainfall is distinctly seen. The secular cycle is here, as in every other record always independent of geographical location.

A continuation of these relations in the future, while not known with certainty, is probable. The conclusion may be drawn that around 1940–1950 the rainfall may again have increased 30 per cent up to the values prevailing around 1880. The average run-off will then be

doubled. Six water-power plants were built on the Ausable River since 1912, at a cost of some $12,000,000. The output may be expected to increase 80 per cent in the above-named period. The effect on the returns on the invested capital is obvious.

The same increase will be felt over a considerable part of the country, and will materially contribute to a renewed popularity of hydroelectric power, which is now lagging behind steam power on account of the greatly increased economy of the latter.

The double sun-spot cycle in rainfall is, as stated above, amplified in stream flow. Figure 6 shows the flow of the Muskegon River, an adjacent watershed. It may be seen that the double sun-spot cycle is plainly visible. By means of this and other graphs the deficiency of hydroelectric power in 1931 is for one power company computed to be 160,000,000 kilowatt-hours, resulting in an increased expenditure for steam coal of some $500,000 for that year. A deficiency in peak capacity of 20,000 kilowatts is also estimated for that year. This means either a new investment of $2,500,000 or else purchase of power elsewhere.

Nevertheless, the weather changes in 1931 will probably alternate as usual without any apparent connection with the Wolf numbers. The latter's unmistakable connection with stream flow, however, will at the same time influence public-utility engineering to the extent of millions of dollars.

The continuity instead of the fortuity of stream flow enables a close estimate of next year's run-off. As described in MONTHLY WEATHER REVIEW, March, 1928, it is possible to make such estimates by extrapolation. The example there given actually checked within 5 per cent. Another estimate made that year placed the mean flow of the Winnipeg River at Great Falls in 1928 at 55 per cent of that during 1927. It actually was deter-
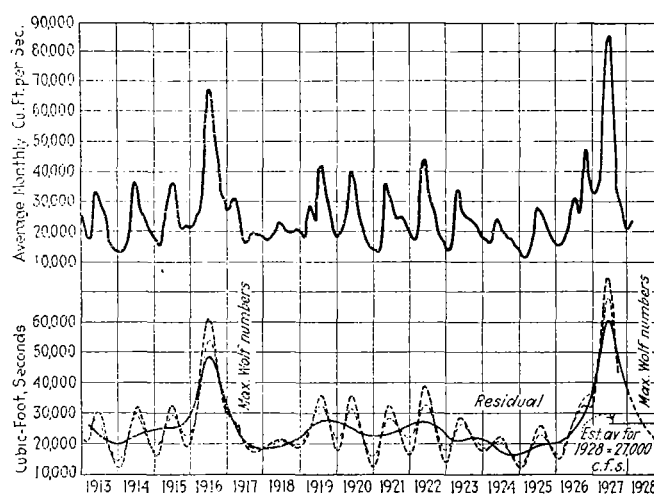


FIGURE 6.—Run-off, Muskegon River, Mich.

mined by the Dominion Bureau of Reclamation and Power to be 60 per cent of that in 1927. The illustration Figure 7 is a graph of the run-off of the Winnipeg River.

Figure 4, the elevation of the Great Salt Lake, the Australian Lake George, and the Wolf numbers, shows likewise close relation with each other. Of interest is the inverse relation of the 11-year cycle in the Wolf numbers and the Great Salt Lake. The graph was made in 1924, and it could then safely be announced that a drop in lake level would take place on account of that

relation. This actually occurred, and a rise culminating in 1936 may well be expected, increasing the lake level at least 4 feet over the present. On account of the simultaneous rise in the Brückner cycle, that figure will probably be exceeded.[1]

Knowledge of the climatic cycles enables the engineer to place a given fragmentary record of stream flow or lake level in its proper relation to the changes occurring during longer periods, and allows an estimate of probable maxima and minima as well as of the probable course in the near future. The old fortuity theory should be
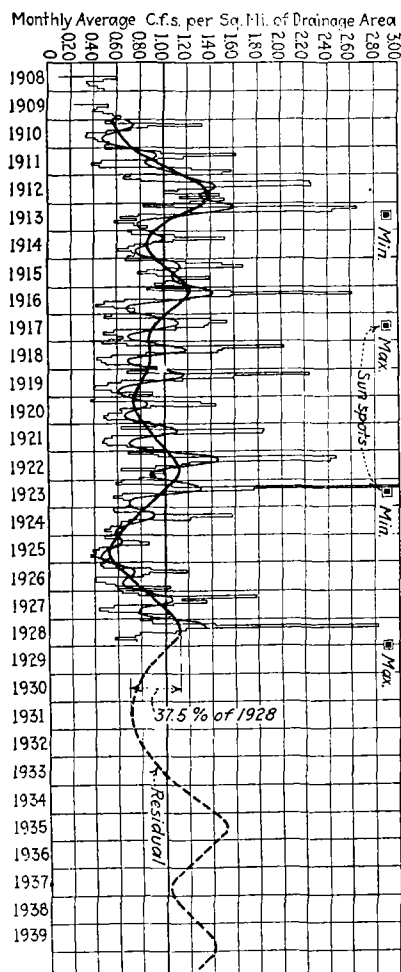


FIGURE 7.—Run-off, Winnipeg River, Canada

replaced by the truer conception of recurrent cycles, which in many locations afford quantitative estimates of future conditions involving large expenditures or investments.

## SUMMARY

(1) Recent climatic changes have too small amplitudes to be of any importance in forecasts of weather. Due to the cumulative as well as amplifying nature of stream flow, they are of great importance in hydraulic engineering.

(2) Correlation of the Wolf numbers and weather is not accepted by many leading meteorologists. Correla-

tion between Wolf number and stream flow, however, can be shown as well as utilized in engineering projects involving large investments.

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[1] The following has been communicated to the editor in a private communication: "I just received from Brisbane, Queensland, the data of the Australian Lake George to date. Remarkably enough, the parallelism with the elevation of the Great Salt Lake is preserved to date. Lake George was dry ground 1905, and is at present more than half full. I also received rainfall data from there which not only show the double Wolf cycle as plainly as Michigan does, but the small amplitude of that cycle around 1905–1910 also occurs in Australia."

[Discussion of this very interesting paper on the part of hydraulic engineers is invited.— EDITOR.]